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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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Additional inventors are being named on the 2nd *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

A METHOD OF SEPARATING NON-METALLIC MATERIAL USING MICROWAVE RADIATION

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ENCLOSED APPLICATION PARTS (check all that apply)

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☐ Application Date Sheet. See 37 CFR 1.76

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Respectfully submitted,

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Date August 31, 2004

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REGISTRATION NO. 24,252 *(if appropriate)*

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A METHOD OF SEPARATING NON-METALIC MATERIAL USING MICROWAVE RADIATION

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FIELD OF THE INVENTION

This invention generally relates to the physical separation of bodies of a brittle non-metallic material preferably of glass sheets and pipes by a *thermal shock* process in which a microwave radiation is used for rapid and selective heating of a local area body. Materials which may be separated by the inventive method include ceramics, semi-conductor wafer materials, glass, quartz, and the like. Material treated by this method can be used in the production of automotive and aircraft glazings, of construction and architectural window glass and the like, of pharmaceutical glass products and the like, of semiconductor wafers and the like, and glass components of various household items and furniture, and the like, structural optical components, and the like, mobile device displays and also in other fields of production and technologies where precision cutting of non-metallic materials is conducted.

SUMMARY OF THE INVENTION

According to the present invention, a method is provided for the separation of bodies of a brittle non-metallic material preferably of glass sheets by a *thermal shock*.. The inventive method utilizes microwave radiation to rapidly and selectively heat the local area of the body to be thermally separated (e.g., a glass sheet, a glass pipe).

The inventive method avoids the use of diamond or tungsten carbide tools that are slow and dusty and do not provide a high quality of cut. The present invention includes making the process easily adaptable for many applications, achieving fast cutting speeds and total separation of the substrate, and eliminating the need for secondary operations. Any kind of brittle material including those having low thermal expansion can be separated by the inventive method.

The main advantages of this high-speed method are reducing manufacturing costs and increasing production rate. Many other specific advantages also exist including but not

limited to cutting complex shapes, the elimination of the cost and issues of grinding, transporting and transferring cut parts for grinding, cleaning cuts.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method of thermally separating a brittle non-metallic material preferably a glass sheet by a thermal shock. In the inventive method a microwave radiation with appropriate frequency and power density is used.

In all of the embodiments of the invention, the frequency (wavelength) of the microwave and power density of the applied microwave radiation are important parameters of the inventive method which must be determined for each type of body material and thickness of bodies processed. The process parameters are chosen so as to accomplish heating of selected area of a body at the required separating propagation path to required temperature in a selected time such that the difference in this temperature and the temperature of the rest of the body material is large enough to create a compressive thermal stress that results in the separating of the body material in the heated area. Flat, non-flat, and pipe types of bodies can be separated using the inventive method.

These parameters and how they are chosen are generally described below for the embodiment of the invention in which a flat glass sheet is exposed to microwave radiation. However, it is understood that the same parameters and their choices are applicable to and must be considered in the alternative embodiments of the invention: cutting glass pipes, semiconductor materials; and like.

The inventive method is generally applicable to the thermal separation of any type of brittle non-metallic material. These treatments include but are not limited to the glass sheet employed in the production of windshields, side windows, and rear windows for vehicles such as automobiles and the like, the production of architectural window glass and related materials, the production of pharmaceutical glass products such as vials, ampoules, pipette, and the like, display glass for mobile devices and the like, glass components of various household items and furniture, and the like as well as semiconductor materials employed in the production of semiconductor wafers and the like.

The cutting of glass, under the action of thermal stresses, consists of the following. When concentrated microwave radiation (microwave beam) is applied to a selected area of the glass sheet, the microwave radiation passes through the glass sheet and heats the area throughout the depth. Compressive stresses are produced in the material being heated because the surrounding areas remain under lower temperature as well as surface temperatures go down just after heating under cooling by cold ambient air. The splitting of the plate glass occurs when these thermally-induced stresses exceed glass tensile strength.

While the tensile strength is determined primarily by the characteristics of glass being processed, the compressive stresses can be increased because they mainly depend on the volume of the glass that is heated up, and the temperature gradients in and around the heated area. The rate of thermal splitting (cutting speed) in its turn is dependent on how rapidly appropriate compressive stresses are created. All this means that the selected area should be heated throughout the thickness and it should be heated rapidly and to high temperature. These conditions can be satisfied by the selection of effective microwave frequency and sufficient power density.

The particular frequency chosen should ensure the heating of the selected glass sheet area throughout the thickness of the glass sheet with maximum coupling of the incident microwave energy in the area. In addition, the chosen frequency should be cost effective and microwave generators for the selected frequency should be readily available at the required power.

If a lower microwave radiation frequency is chosen for irradiation, it creates a lower temperature differential across the thickness because of the low absorption of the microwave radiation by the glass (see, for example, E. B. Shand <u>Glass Engineering Handbook, 2nd Edition</u> pages 73-75). Thus, lower frequency microwave radiation allows the heating of both outer surfaces to approximately the same temperature that increases the compressive stresses. However, the lower microwave radiation frequency requires a more powerful microwave source to achieve the desirable power density that will provide rapid enough heating. The necessary power density drastically rises if the microwave

frequency is lower than 10 GHz, and creates many technical and economic problems. Therefore higher microwave frequency is more preferable. However, the current state-of-the-art level of microwave technique makes it very difficult and very expensive to install a power system with a frequency higher than 1000 GHz. Thus, the effective microwave frequency range for the present invention is between about 10 GHz and about 1000 GHz. The preferable frequency is such that the skin layer for this frequency in the body material approximately equals its thickness. In this case heating across the thickness is guarantied. The most preferable microwave frequency range for the present invention is when the incident microwave wavelength λ in the glass being heated ($\lambda=c_l/f$, where f is frequency and c_l is speed of light in a vacuum) is selected in and around the glass thickness range that allows a drastic increase in the efficiency of the applied microwave radiation because the standing wave appears to be inside of the glass sheet.

In the embodiments of the invention discussed above, a microwave absorbent having a greater microwave absorption than the body material at a selected microwave irradiation frequency is applied along the required separating propagation path. This allows increasing the cutting speed and accuracy because higher absorption increases the heating rate.

Heating rate increases more if microwave irradiation frequency is selected such that the skin layer for this frequency in the absorbent approximately equals its thickness. The absorbent is selected from the group consisting of semi-metals, carbides, nitrides, oxides, sulfides, silicides, boron, carbon, graphite and metals.

Cutting speed increases also if selected heated area and its surrounds of the body of material is cooled during exposure to microwave as well as before and after exposure because this increases compressive stresses. A stream of cold gas, for example, liquid nitrogen steam that blows on the body, can be used for said cooling because gases are transparent for microwave. The body can be cooled by placing it on a cooled metal support and/or by placing a cold correspondently shaped plate on the surface that is exposed to microwave. The material of said plate is transparent to microwave and is selected from the group consisting of oxide ceramics, nitride ceramics, quartz and diamond.

Accuracy and cutting speed can be increased if the exposure to microwave radiation is conducted through a metal mask with an opening along the required propagation path

It has been further found that the maximal speed can be achieved by irradiating applied absorbent and/or irradiating through the mask, all at once.

Microwave radiation with the necessary frequency and power density can be achieved using generators such as the gyrotron, klystron, traveling wave tube, and backward wave oscillator, and the like.

The main distinction of the inventive method is high cutting speed, high quality of cut, and eliminating the need for secondary operations. Any kind of brittle material including those having low thermal expansion can be separated by the inventive method.

The present invention has been described in an illustrative manner. It is to be understood that the terminology that has been used is intended to be in the nature of words of description rather than of limitation. Many modifications and variations of the present invention are possible in light of the above teachings. Therefore, within the scope of the appended claims, the present invention may be practiced other than as specifically described.

What is claimed is:

1. A method of separating a body of brittle non-metallic material by thermal shock comprising exposing the body to concentrated microwave radiation of an effective frequency and sufficient power density to heat at least one selected area of the body at the required separating propagation path to required temperature in a selected time wherein the selected power density, power and exposure time are sufficient to ensure that the selected area is heated to a temperature higher than the rest of the body material temperature such that the difference in said

temperatures is large enough to create a compressive thermal stress that results in the separating of the body material.

2. The method in accordance with claims 1 wherein the microwave irradiation frequency is between about 10GHz to about 1000GHz.

3. The method in accordance with claim 1 wherein the preferable microwave irradiation frequency is selected such that the skin layer for this frequency in the body material is approximately equal to its thickness.

4. The method in accordance with claim 1 wherein the most preferable microwave frequency range is when the incident microwave wavelength in the body material being heated is selected in and around the body thickness range.

5. The method in accordance with claim 1 wherein a microwave absorbent having a greater microwave absorption than the body material at a selected microwave irradiation frequency is applied along the required separating propagation path.

6. The method in accordance with claims 1, 5 wherein the selected heated area and its surrounds of the body of material is cooled during, and optionally prior and after, exposure to microwave.

7. The method in accordance with claims 1, 5 wherein the exposure to microwave radiation is carried out through a metal mask with an opening along the required propagation path.

8. The method in accordance with claim 5 wherein the microwave absorbent is selected from the group consisting of semi-metals, carbides, nitrides, oxides, sulfides, silicides, boron, carbon, graphite and metals.

9. The method in accordance with claim 5 wherein the microwave irradiation frequency is selected such that the skin layer for this frequency in the absorbent is approximately equal to its thickness.

10. The method in accordance with claim 5 wherein the entire applied absorbent is exposed to microwave all at once.

11. The method in accordance with claim 6 wherein cold gas is blown on and around the body.

12. The method in accordance with claim 6 wherein the body is placed on a cold metal support.

13. The method in accordance with claim 6 wherein the microwave is exposed through a cold, and transparent for microwave, material that is lying upon the body's irradiated surface.

14. The method in accordance with claim 7 wherein the required propagation path is exposed to microwave all at once.

15. The method in accordance with claim 2, 3, 8, and 10 wherein the source of microwave radiation is selected from the group consisting of gyrotron, klystron, magnetron, traveling wave tube, and backward wave oscillator.

16. The method in accordance with claim 14 wherein the transparent material is selected from the group consisting of oxide ceramics, nitride ceramics, quartz and diamond .

ABSTRACT

A method of high speed cutting of non-metallic materials, preferably glass, is described. In the inventive method a concentrated microwave radiation with appropriate frequency and power density is chosen so as to accomplish heating of at least one selected area of the body at the required separating propagation path to required temperature in a selected short time while ensuring that this temperature is large enough to create a compressive thermal stress that results in the separating of the body material.